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Claims

[c1] 1. A plasma processing apparatus for performing plasma processing with respect to a sample to be processed in a reaction vessel, comprising:
microwave generating means that generates microwaves;
a first dielectric that is connected to the microwave generating means, the first dielectric having a rectangular section that extends along the surface of the sample to be processed, and which makes an electric field strength distribution of the microwaves generated from the microwave generating means substantially uniform along the surface to be processed of the sample;
a slot plate that is provided between the reaction vessel and the first dielectric and having a plurality of first slots formed therein, the slot plate maintaining or further enhancing the uniformity of the electric field strength distribution of the microwaves in the first dielectric;
a second dielectric that is provided between the slot plate and the reaction vessel and which maintains or further enhances the uniformity of the electric field strength distribution of the microwaves supplied from the slot plate; and
processing means that processes the sample using

plasma generated in the reaction vessel by the microwaves.

[c2] 2. The plasma processing apparatus according to claim 1, wherein
a section of the second dielectric that extends along the surface of the sample to be processed is rectangular.

[c3] 3. The plasma processing apparatus according to claim 1, wherein
the reaction vessel is formed such that a section thereof that extends along the surface of the sample to be processed is rectangular.

[c4] 4. The plasma processing apparatus according to claim 1, wherein
the microwave generating means include an antenna in which a section that extends along the surface of the sample to be processed is rectangular, and the antenna is in contact with the first dielectric.

[c5] 5. The plasma processing apparatus according to claim 1, wherein
the size and shape of the first slots are substantially the same and are arranged in substantially the same direction, and a distance L_1 between centers of adjacent first slots substantially satisfies the equation $L_1 = n_{L1} \lambda_1$, in

which λ_1 represents the wavelength of microwaves in the first dielectric and n_{L1} represents an integer of 1 or more.

[c6] 6. The plasma processing apparatus according to claim 1, wherein
the first slots have substantially the same size and the same shape, and are arranged in a linearly symmetrical manner with respect to either one of two axes that extend along the slot plate and orthogonal to each other, and a distance L_2 between centers of adjacent first slots substantially satisfies the equation $L_2 = n_{L2}(\lambda_1/2)$, in which λ_1 represents the wavelength of microwaves in the first dielectric and n_{L2} represents an integer of 1 or more.

[c7] 7. The plasma processing apparatus according to claim 1, wherein
two opposing sides of the first dielectric are parallel in a direction that extends along the surface of the sample to be processed, and a distance L_{d1} between the two opposing sides of the first dielectric substantially satisfies the equation $L_{d1} = n_{d1\ \lambda1}(/2)$, in which λ_1 represents the wavelength of microwaves in the first dielectric and n_{d1} represents an integer of 1 or more.

[c8] 8. The plasma processing apparatus according to claim

2, wherein

two opposing sides of the second dielectric are parallel in a direction that extends along the surface of the sample to be processed, and a distance L_{d2} between the two opposing sides of the second dielectric substantially satisfies the equation $L_{d2} = n_{d2}(\lambda_2/2)$, in which λ_2 represents the wavelength of microwaves in the second dielectric and n_{d2} represents an integer of 1 or more.

[c9] 9. The plasma processing apparatus according to claim 7, wherein

a dielectric constant of the first dielectric is substantially the same as that of the second dielectric.

[c10] 10. The plasma processing apparatus according to claim 3, wherein

two opposing sides of the reaction vessel are parallel in a direction that extends along the surface of the sample to be processed, and a length L_{p1} of the two opposing sides of the reaction vessel substantially satisfies the equation $L_{p1} = n_{p1}(\lambda_p/2)$, in which λ_p represents the wavelength of microwaves in the reaction vessel and n_{p1} represents an integer of 1 or more.

[c11] 11. The plasma processing apparatus according to claim 2, wherein

two opposing sides of an introduction surface that is in

contact with the first dielectric of the microwave generating means are parallel, a plurality of second slots through which the microwaves are introduced from the microwave generating means to the first dielectric are provided in the introduction surface, the central positions of the second slots are alternately arranged on two axes along the two opposing sides of the introduction surface, and a distance L_5 between the two axes substantially satisfies the equation $L_5 = n_{L5}(\lambda_1/2)$, in which λ_1 represents the wavelength of microwaves in the first dielectric and n_{L5} represents an integer of 1 or more.

[c12] 12. The plasma processing apparatus according to claim 11, wherein

a distance L_4 in an axial direction between centers of the second slots alternately arranged on the two axes substantially satisfies the equation $L_4 = n_{L4}(\lambda_1/2)$,in which λ_1 is the wavelength of microwaves in the first dielectric and n_{L4} is an integer of 1 or more.

[c13] 13. The plasma processing apparatus according to claim 11, wherein

a distance D1 between end faces that extend along the two opposing sides of the introduction surface of the first dielectric and the two axes substantially satisfies the equation $D1 = n_{D1}(1/4)\ \lambda_1$, in which λ_1 represents the wavelength of microwaves in the first dielectric and n_{D1}

represents an integer of 1 or more.

[c14] 14. The plasma processing apparatus according to claim 1, wherein
a thickness of the slot plate is 1 mm or more.

[c15] 15. The plasma processing apparatus according to claim 14, wherein
a thickness of the slot plate is 3 mm or more.

[c16] 16. The plasma processing apparatus according to claim 14, wherein
the first slots of the slot plate are rectangular, and a length L_7 of longer sides of the first slots substantially satisfies the equation $L_7 \geq (3/8)\ _{\lambda 1}$, in which $_{\lambda 1}$ represents the wavelength of microwaves in the first dielectric.

[c17] 17. The plasma processing apparatus according to claim 16, wherein
the length L_7 of the longer sides of the first slots substantially satisfies the equation $L_7 \geq (1/2)\lambda_1$, in which λ_1 represents the wavelength of microwaves introduced to the slot plate.

[c18] 18. The plasma processing apparatus according to claim 17, wherein
the length L_7 of the longer sides of the first slots sub-

stantially satisfies the equation $L_7 = (1/2)\,\lambda_1$, in which λ_1 represents the wavelength of microwaves introduced to the slot plate.

[c19] 19. A plasma processing apparatus for performing plasma processing with respect to a sample to be processed in a reaction vessel, comprising:

microwave generating means for generating microwaves;

a first dielectric that is connected to the microwave generating means, the first dielectric having a section that is a rectangular shape in which two opposing sides thereof are parallel to each other, and extends along a surface of a sample to be processed and makes an electric field strength distribution of microwaves generated from the microwave generating means substantially uniform along a surface of the sample to be processed; and

processing means that processes the sample using plasma generated in the reaction vessel by the microwaves;

wherein a distance L_{d11} between the two opposing sides of the first dielectric in a direction along the surface of the sample to be processed substantially satisfies the equation $L_{d11} = n_{d11}(\lambda_1/2)$, in which λ_1 represents the wavelength of microwaves in the first dielectric and n_{d11} represents an integer of 1 or more.

[c20] 20. The plasma processing apparatus according to claim 19, further comprising:

a slot plate that is provided between the reaction vessel and the first dielectric and in which at least one slot is formed, the slot plate maintaining or further enhancing uniformity of the electric field strength distribution of microwaves in the first dielectric; and

a second dielectric that is provided between the slot plate and the reaction vessel, the second dielectric having a section that is a rectangular shape in which two opposing sides are parallel to each other, extends along a surface of a sample to be processed, and maintains or further enhances uniformity of the electric field strength distribution of microwaves supplied from the slot plate;

wherein a distance L_{d22} between the two opposing sides of the second dielectric in a direction that extends along the surface of the sample to be processed substantially satisfies the equation $L_{d22} = n_{d22}(\lambda_2/2)$, in which λ_2 represents the wavelength of microwaves in the second dielectric and n_{d22} represents an integer of 1 or more.

[c21] 21. The plasma processing apparatus according to claim 19, wherein

a section of the reaction vessel is a rectangular shape that extends along a surface of the sample to be processed and in which two opposing sides of the reaction

vessel are parallel to each other, and a length L_{p2} of the two opposing sides of the reaction vessel substantially satisfies the equation $L_{p2} = n_{p2}(\lambda_p/2)$, in which λ_p represents the wavelength of microwaves in the reaction vessel and n_{p2} represents an integer of 1 or more.

[c22] 22. The plasma processing apparatus according to claim 20, wherein
a dielectric constant of the first dielectric is substantially the same as that of the second dielectric.

[c23] 23. The plasma processing apparatus according to claim 20, wherein
a wavelength λ_1 of microwaves in the first dielectric and a wavelength λ_2 of microwaves in the second dielectric substantially satisfy the equation $\lambda_1/2 = m(1/2)\lambda_2$, in which λ_1 represents the wavelength of microwaves in the first dielectric, λ_2 represents the wavelength of a microwave in the second dielectric, and m represents an integer of 1 or more.

[c24] 24. The plasma processing apparatus according to claim 20, wherein
a wavelength λ_1 of microwaves in the first dielectric, a wavelength λ_2 of microwaves in the second dielectric, and a wavelength λ_p of microwaves in the reaction vessel substantially satisfy the equations $\lambda_1/2 = m(1/2)\lambda_2$ and

$\lambda_1/2 = k(1/2)\lambda_P$, in which λ_1 represents the wavelength of microwaves in the first dielectric, λ_2 represents the wavelength of microwaves in the second dielectric, λ_P represents the wavelength of microwaves in the reaction vessel, and m, k represent an integer of 1 or more.

[c25] 25. A plasma processing apparatus for performing plasma processing with respect to a sample to be processed in a reaction vessel, comprising:
microwave generating means for generating microwaves;
a dielectric that is connected to the microwave generating means, is formed into a plate-like shape that extends along a surface of the sample to be processed, and makes an electric field strength distribution of the microwaves generated from the microwave generating means substantially uniform along a surface of the sample to be processed; and
processing means that processes the sample using plasma generated in the reaction vessel by the microwaves;
wherein a plurality of introduction portions through which the microwaves are introduced from the microwave generating means to the dielectric are provided in an introduction surface that is in contact with the dielectric of the microwave generating means, the central positions of the introduction portions are arranged on a

plurality of axes on the introduction surface that extend in the same direction, and antinodes or nodes of the microwaves in the dielectric are positioned at each position of the axes.

[c26] 26. The plasma processing apparatus according to claim 25, wherein
the dielectric is formed such that a section thereof that extends along the surface of the sample to be processed is rectangular, and a distance L_8 between the axes substantially satisfies the equation $L_8 = n_{L8}(\lambda_1/2)$, in which λ_1 represents the wavelength of microwaves in the dielectric and n_{L8} represents an integer of 1 or more.

[c27] 27. The plasma processing apparatus according to claim 26, wherein
the dielectric is formed such that a section that extends along the surface of the sample to be processed is rectangular or square, and the axes extend in a direction along two opposing sides of the dielectric.

[c28] 28. The plasma processing apparatus according to claim 27, wherein
the introduction surface is formed into a rectangular or square shape, and the axes are linearly symmetrical with respect to a central axis that extends toward the sides of the introduction surface.

[c29] 29. The plasma processing apparatus according to claim 28, wherein

a distance D2 between end faces of the dielectric and the axes substantially satisfies the equation $D2 = n_{D2}(1/4)\lambda_1$, wherein λ_1 represents the wavelength of microwaves in the dielectric and n_{D2} represents an integer of 1 or more.

[c30] 30. The plasma processing apparatus according to claim 25, wherein

a section of the dielectric that extends along the surface of the sample to be processed is rectangular, the introduction portions are alternately arranged on the two axes, and a distance L_9 in an axial direction between the centers of the introduction portions alternately arranged on the two axes substantially satisfies the equation $L_9 = n_{L9}(\lambda_1/2)$, in which λ_1 represents the wavelength of microwaves in the dielectric and n_{L9} represents an integer of 1 or more.

[c31] 31. The plasma processing apparatus according to claim 26, wherein

an H-branched waveguide is further provided between the microwave generating means and the dielectric, and the introduction surface is divided into at least two.

[c32] 32. The plasma processing apparatus according to claim

31, wherein

when the microwaves introduced from each of the at least two divided introduction surfaces to the dielectric have a phase identical to the other introduction surfaces, a distance L_{10} between the introduction portions in adjacent introduction surfaces substantially satisfies the equation $L_{10} = 2n_{L10}(\lambda_1/2)$, in which λ_1 represents the wavelength of microwaves in the dielectric and n_{L10} represents an integer of 1 or more.

[c33] 33. The plasma processing apparatus according to claim 31, wherein

when the microwaves introduced from each of the at least two divided introduction surfaces to the dielectric have opposite phases, a distance L_{10} between the introduction portions in adjacent introduction surfaces substantially satisfies the equation $L_{10} = (2n_{L10}+1)(\lambda_1/2)$, in which λ_1 represents the wavelength of microwaves in the dielectric and n_{L10} represents an integer of 1 or more.

[c34] 34. The plasma processing apparatus according to claim 26, wherein

an E-branched waveguide is further provided between the microwave generating means and the dielectric, and the introduction surface is divided into at least two.

[c35] 35. The plasma processing apparatus according to claim

34, wherein

when the microwaves introduced from each of the at least two divided introduction surfaces to the dielectric have identical phases, a distance L_{10} between the introduction portions in adjacent introduction surfaces substantially satisfies the equation $L_{10} = (2n_{L10}+1)(\lambda_1/2)$, in which λ_1 represents the wavelength of microwaves in the dielectric and n_{L10} represents an integer of 1 or more.

[c36] 36. The plasma processing apparatus according to claim 34, wherein

when the microwaves introduced from each of the at least two divided introduction surfaces to the dielectric have opposite phases, a distance L_{10} between the introduction portions in adjacent introduction surfaces substantially satisfies the equation $L_{10} = 2n_{L10}(\lambda_1/2)$, in which λ_1 represents the wavelength of microwaves in the dielectric and n_{L10} represents an integer of 1 or more.

[c37] 37. A plasma processing apparatus for performing plasma processing with respect to a sample to be processed in a reaction vessel, comprising:

microwave generating means for generating microwaves;

a slot plate that is provided between the microwave generating means and the reaction vessel and in which a plurality of slots are formed, and that makes an electric field strength distribution of the microwaves generated

from the microwave generating means substantially uniform along the surface of the sample to be processed;
a first dielectric that is provided between the slot plate and the reaction vessel, and maintains or further enhances uniformity of the electric field strength distribution of the microwaves supplied from the slot plate; and
processing means that processes the sample using plasma generated in the reaction vessel by the microwaves,
wherein a thickness of the slot plate is 1 mm or more.

[c38] 38. The plasma processing apparatus according to claim 37, wherein
a second dielectric is further provided between the microwave generating means and the slot plate.

[c39] 39. The plasma processing apparatus according to claim 37, wherein
a thickness of the slot plate is 3 mm or more.

[c40] 40. The plasma processing apparatus according to claim 37, wherein
the slots of the slot plate are rectangular, and a length L_{11} of longer sides of the slots substantially satisfies the equation $L_{11} \geq (3/8)\lambda_A$, in which λ_A represents the wavelength of microwaves introduced to the slot plate.

[c41] 41. The plasma processing apparatus according to claim 40, wherein

the length L_{11} of the longer sides of the slots substantially satisfies the equation $L_{11} \geq (1/2)\ \lambda_A$, in which λ_A represents the wavelength of microwaves introduced to the slot plate.

[c42] 42. The plasma processing apparatus according to claim 41, wherein

the length L_{11} of the longer sides of the slots substantially satisfies the equation $L_{11} = (1/2)\ \lambda_A$, in which λ_A represents the wavelength of microwaves introduced to the slot plate.

[c43] 43. The plasma processing apparatus according to claim 38, wherein

sections along the surface to be processed of the sample of the first dielectric and the second dielectric are rectangular.

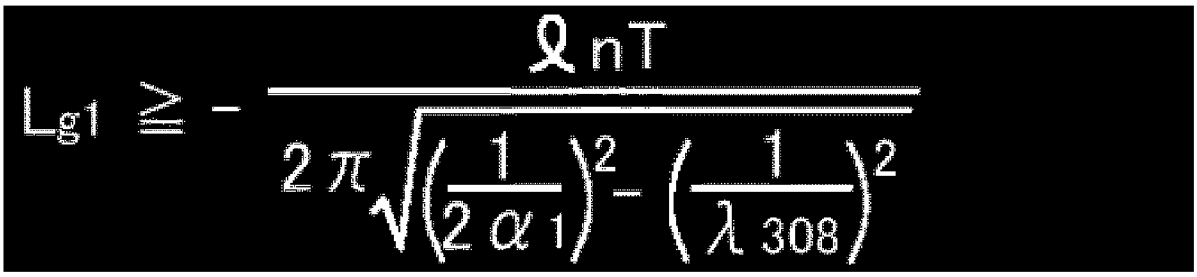
[c44] 44. The plasma processing apparatus according to claim 43, wherein

the slots have substantially a same size and a same shape and are arranged in substantially the same direction, and a distance L_{13} between centers of adjacent slots substantially satisfies the equation $L_{13}=n_{L13}\lambda_2$, wherein λ_2 represents the wavelength of microwaves in

the second dielectric, and n_{L13} represents an integer of 1 or more.

[c45] 45. The plasma processing apparatus according to claim 43, wherein
the slots have substantially the same size and same shape and are arranged in a linearly symmetrical manner with respect to either one of the axes that extend along the slot plate and orthogonal to each other, and a distance L_{14} between centers of adjacent slots substantially satisfies the equation $L_{14} = n_{L14}(\lambda_2/2)$, in which λ_2 represents the wavelength of microwaves in the second dielectric, and n_{L14} represents an integer of 1 or more.

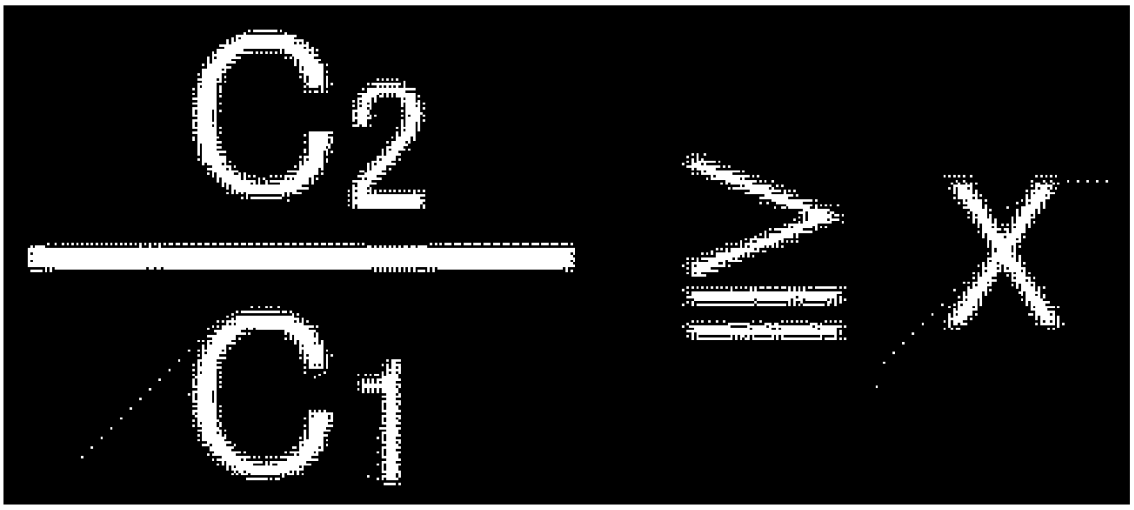
[c46] 46. A plasma processing apparatus comprising:
microwave generating means;
a reaction vessel that is connected to the microwave generating means, in which a plasma is generated by microwaves generated from the microwave generating means;
an introduction channel through which a gas is supplied to the reaction vessel; and
at least one nozzle connecting the reaction vessel and the introduction channel,
wherein a transmission T of the microwaves from the reaction vessel to the nozzle substantially satisfies the equation



wherein Lg_1 represents the length of a nozzle in a direction in which gas therein travels, α_1 represents an outer diameter of the nozzle in a direction perpendicular to the direction in which the gas therein travels, and λ represents the wavelength of microwaves in the reaction vessel.

[c47] 47. The plasma processing apparatus according to claim 46, wherein

a ratio of a conductance C_1 of a gas in the nozzle and a conductance C_2 of a gas in the introduction channel substantially satisfies the equation



wherein X is the number of the nozzles connected to the introduction channel.

[c48] 48. The plasma processing apparatus according to claim 47, wherein
the transmission T is 1% or less.

[c49] 49. The plasma processing apparatus according to claim 46, further comprising:
a first dielectric that is connected to the microwave generating means, the first dielectric section having a rectangular section that extends along a surface of the sample to be processed and that makes an electric field strength distribution of the microwaves generated from the microwave generating means substantially uniform along the surface to be processed of the sample that is to be subjected to plasma processing in the reaction vessel; and
processing means that processes the sample using the plasma.

[c50] 50. The plasma processing apparatus according to claim 49, further comprising:
a slot plate that is provided below the first dielectric and in which at least one slot is formed, and that retains or further enhances the uniformity of the electric field strength distribution of the microwaves in the first dielectric; and
a second dielectric having a rectangular section that extends along a surface of the sample to be processed, is

provided between the slot plate and the reaction vessel, and which maintains or further enhances the uniformity of the electric field strength distribution of the microwaves supplied from the slot plate.